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The Associations between Environmental Quality and Mortality in the Contiguous United States, 2000-2005

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Abstract

Background: Assessing cumulative effects of the multiple environmental factors influencing mortality remains a challenging task.

Objectives: This study aimed to examine the associations between cumulative environmental quality and all-cause and leading cause-specific (heart disease, cancer, and stroke) mortality rates.

Methods: We used the overall Environmental Quality Index (EQI) and its five domain indices (air, water, land, built and sociodemographic) to represent environmental exposure. Associations between the EQI and mortality rates (CDC WONDER) for counties in the contiguous United States (n=3109) were investigated using multiple linear regression models, and random intercept, random slope hierarchical models. Urbanicity, climate and their combination were used to explore the spatial patterns in the associations.

Results: We found one standard deviation increase in the overall EQI (worse environment) was associated with a mean 3.22% (95% CI: 2.80%, 3.64%) increase in all-cause mortality, a 0.54 % (-0.17%, 1.25%) increase in heart disease mortality, a 2.71% (2.21%, 3.22%) increase in cancer mortality, and a 2.25% (1.11%, 3.39%) increase in stroke mortality. Among environmental domains, the associations ranged from -1.27% (-1.70%, -0.84%) to 3.37% (2.90%, 3.84%) for all-cause mortality, -2.62% (-3.52%, -1.73%) to 4.50% (3.73, 5.27%) for heart disease mortality, -0.88% (-2.12%, 0.36%) to 3.72% (2.38%, to 5.06%) for stroke mortality, and -0.68% (-1.19%, -0.18%) to 3.01% (2.46%, 3.56%) for cancer mortality. Air had the largest associations with all-cause, heart disease, and cancer mortality, while the sociodemographic index had the largest association with stroke mortality. Across the urbanicity gradient, no consistent trend was found. Across climate regions, the associations ranged from 2.29% (1.87%, 2.72%) to 5.30% (4.30%,

6.30%) for overall EQI and higher associations were generally found in dry area for both overall EQI and domain indices.

Conclusions: These results suggest that poor environmental quality, particularly air quality, was associated with increased mortality, and that associations vary by urbanicity and climate regions.

Introduction

Many environmental factors influence mortality. The majority of the studies investigating environmental effects on mortality have focused on air pollutants and show that exposure to air pollutants is linked with increased risk of mortality (e.g. Krall et al. 2013; Tao et al. 2012; Zanobetti and Schwartz 2009). Associations between water pollutants and mortality have also been reported, particularly in the vicinity of polluted water environments (Harmon and Coe 1993; Hendryx et al. 2012; Ren et al. 2015). A few studies also reported associations between mortality and other aspects of environment quality. Higher levels of underground radon were found to be linked with higher risk of mortality due to lung cancer and chronic obstructive pulmonary disease (Turner et al. 2012a, b). Higher cancer mortality was found in the vicinity of incinerators and hazardous wastes sites (Garcia-Perez et al. 2013). Additionally, mortality disparities have been observed across sociodemographic environments, such as income, education, and immigration (Ezzati et al. 2008, Pearce et al. 2010, 2011). Hence, environmental conditions are clearly important factors affecting human mortality.

The influence of different environmental factors often occur in tandem; however, few studies have explored the impact of multiple exposures across environmental domains on mortality (Pearce et al. 2010, 2011). Most mortality studies have focused on the independent effect of a single variable (e.g. the association between one air pollutant and mortality) (Lu et al. 2015; Schwartz et al. 2015), or the combined effects of a few (usually 2-3) variables within the same environmental domain (e.g. fine and coarse particulate matter in the air) (Tao et al. 2012; Zanobetti and Schwartz 2009). A few studies have assessed the overall impact of water environment on mortality (Hendryx et al. 2012; Ren et al. 2015). While some work has been

conducted outside the United States (U.S.) (Pearce et al. 2010, 2011), the relationship between multiple environmental factors and mortality in the U.S. remains under-explored.

Mortality has also been observed to vary spatially, and some of that spatial variability occurs across rural – urban differences. Higher mortality has been observed in non-metropolitan compared to metropolitan areas (Cossman et al. 2010). However, the underlying causes of this difference remain unclear. It seems likely that urban and rural residents are exposed to different environments; for instance, urban residents may experience higher amounts of air pollution while rural residents may be exposed to more agricultural pesticide usage. The health impact of environmental quality may both result from and differ across the rural-urban continuum. However, most of the studies about environmental impact on mortality only focused on urban areas (Krall et al. 2013; Zanobetti and Schwartz 2009). Therefore, analyses exploring the differences in the environmental impact on mortality across urbanicity are justified.

The associations between cumulative environmental quality and mortality may also be influenced by climate. Previously, temperature was found to modify the association between air pollution and mortality (Kim et al. 2015). Associations between particulate matter and mortality also differed across climate regions (Zanobetti and Schwartz 2009). With climate and sociodemographic environments, persons with lower income were less resistant to extreme weather conditions such as heat/cold waves and natural disasters (Nordio et al. 2015; O'Neill et al. 2005). However, studies about the spatial variation in environmental impacts on mortality across different climates are rare, and efforts are needed to target places with high environmental burden on mortality

To address these gaps, we used the Environmental Quality Index (EQI) to assess the cumulative environmental effect on mortality, and the spatial patterns of that effect. The EQI was constructed to represent county-level ambient environmental quality across the U.S. (Lobdell et al. 2011; Messer et al. 2014). It encompasses an overall index and five domain indices (air, water, land, built and sociodemographic). Here, we investigated the associations between the overall EQI and all-cause and cause-specific mortality rates for the contiguous U.S. We further examined the associations for EQI domain indices to assess different effects across environment aspects. Finally, we investigated spatial patterns of associations by urbanicity and climate.

Methods

Mortality outcome data

Age-adjusted mortality rates for the contiguous U.S. in 2000-2005 were obtained from the U.S. Centers for Disease Control and Prevention (CDC), Wide-ranging Online Data for Epidemiologic Research (U.S. CDC 2015). Age-adjusted mortality rates were weighted averages of the age-specific death rates and they were used to account for different age structures among populations (Curtin and Klein 1995). The mortality rates for counties with fewer than 10 deaths were suppressed by CDC to protect privacy and ensure data reliability; only counties with 10+ deaths were included in the analyses. The underlying cause of mortality was specified with the 10th version of International Statistical Classification of Diseases and Related Health Problems (ICD-10) (World Health Organization 2015). In this study, we focused on all-cause mortality rate (A00-R99), and mortality rates due to the three leading causes: heart disease (I00-I09, I11, I13, and I20-I51), cancer (C00-C97), and stroke (I60-I69) (Heron 2013). We excluded mortality due to external causes for all-cause mortality, as in many previous studies (e.g. Pearce et al. 2010,

2011; Zanobetti and Schwartz 2009), because external causes of mortality were less likely to be related to environmental quality. We also focused on the contiguous U.S. because the number of counties with available cause-specific mortality rates were small in Hawaii and Alaska. County-level rates were available for 3101 of the 3109 counties in the contiguous U.S. (99.7%) for all-cause mortality, 3067 (98.6%) counties for heart disease mortality, 3057 (98.3%) counties for cancer mortality, and 2847 (91.6%) counties for stroke mortality.

Environmental Quality Index (EQI)

The EQI was used to represent cumulative environmental quality for 2000-2005 (Figure 1). Methods for the EQI have been previously published (Lobdell et al. 2011; Messer et al. 2014). Briefly, the EQI was constructed using principal component analysis (PCA) to reduce 219 environmental variables into five domain-specific (air, water, land, built and sociodemographic) indices. These indices were then included in a second PCA to produce an overall environmental quality index. The 18 data sources for EQI ranged from the Air Quality System in the air domain to Uniform Crime Reports in the sociodemographic domain; a complete list is published in Lobdell et al. (2011) and U.S. EPA (2014). The original EQI covered the entire U.S. at the county level. The summary statistics of the EQI for the contiguous U.S. are listed in the supplementary materials (Table S1). Higher EQI values represent worse environmental quality. The EQI was constructed for the entire six-year period of 2000-2005; due to data unavailability (infrequency of update), single year EQIs were not constructed (Messer et al. 2014). Overall and domain-specific EQI data were downloaded from U.S. Environmental Protection Agency (U.S. EPA 2015).

Covariates

We used county-level Rural-Urban Continuum Codes (RUCC) to account for variability across urbanicity (U.S. Department of Agriculture 2015). The 9 RUCC groups were condensed into 4 groups as has been done elsewhere: metropolitan urbanized (RUCC1), non-metropolitan urbanized (RUCC2), less urbanized (RUCC3), and thinly populated (RUCC4) areas (Langlois et al. 2010; Luben et al. 2009; Messer et al. 2010) (Figure 1). The exclusion of counties with fewer than 10 deaths had the largest impact on stroke mortality in thinly populated areas (RUCC4) with 217 counties removed (about 20% counties in this category), while for other types of mortality or other RUCCs fewer than 50 counties were excluded. We also used Koppen climate regions to assess potential variability under different climates (Kottek et al. 2006). Originally, counties were classified into 18 climate regions in the contiguous U.S according to their annual and monthly averages of temperature and precipitation. Here, the 18 climate regions were condensed into 6 groups including dry, dry continental, hot summer continental, humid subtropical, Mediterranean, and warm summer continental regions as in a previous study (Figure 1 and Table S2) (Zanobetti and Schwartz 2009). The exclusion of counties with fewer than 10 deaths had the largest impact on stroke mortality in dry continental region with 68 counties removed (about 20%). We further constructed a variable combining the RUCC and climate region categories to explore the variation in the associations linked with both urbanicity and climate (24 groups). This variable represented unique RUCC in each climate region, for example metropolitan urbanized area in humid subtropical region. The RUCCs, climate regions, and their combination were included as regional cluster variables (random effects) in hierarchical models. The number of counties for each RUCC, climate region, and their combination can be found in Tables 1 and S3. Other county-level sociodemographic variables (not used in the sociodemographic index) adjusted in the analysis included percent of white population and population density (U.S.

Census Bureau 2000, 2012). Estimated county-level cigarette smoking from Dwyer-Lindgren et al. (2014) and alcohol consumption from Dwyer-Lindgren et al. (2015) were also used for adjustment. These data were available for all counties in the U.S.

Statistical analysis

We assessed the relationship between county-level exposures and mortality rates. We analyzed the associations between overall EQI and mortality, and between EQI domain indices and mortality. For both overall EQI and domain indices, we performed the following analyses: (1) a multiple linear regression model to assess the average effects for the contiguous U.S.; (2) a random intercept, random slope hierarchical model clustered by the condensed RUCC category to assess variation in associations by urbanicity; (3) a random intercept, random slope hierarchical model clustered by the condensed climate regions to assess variation linked with climate; and (4) a random intercept, random slope hierarchical model clustered by the RUCC-climate combination to assess variation linked with both urbanicity and climate. Models were built separately for all-cause and cause-specific mortality rates. For domain-specific models, all indices were included simultaneously. All the mortality rates in the model were log transformed, and the EQI indices were rescaled (mean = 0 and standard deviation = 1) to facilitate model convergence and interpretation. Following these transformations, the results were reported as percent difference in mortality rate and 95% confidence interval (95% CI) per 1 standard deviation (SD) increase in the overall EQI or domain specific EQI indices. All the analyses were performed in R 3.2.0 with the Package ‘lme4’ (Bates et al. 2015).

An example of the overall EQI model clustered by RUCC for all-cause mortality was

$$\log(y_{i,j}) = \alpha_{0,i} + \alpha_1 \times \text{smoking}_{i,j} + \alpha_2 \times \text{alcohol}_{i,j} + \alpha_3 \times \text{white\%}_{i,j} + \alpha_4 \times \text{popden}_{i,j} \\ + \beta_i \times \text{overallEQI}_{i,j} + \varepsilon_{i,j}$$

$$\begin{pmatrix} \alpha_{0,i} \\ \beta_i \end{pmatrix} \sim N \left(\begin{pmatrix} \mu_{\alpha 0} \\ \mu_{\beta} \end{pmatrix}, \begin{pmatrix} \sigma_{\alpha 0}^2 & \rho \sigma_{\alpha 0} \sigma_{\beta} \\ \rho \sigma_{\alpha 0} \sigma_{\beta} & \sigma_{\beta}^2 \end{pmatrix} \right)$$

Where y was county-level age-adjusted all-cause death rate, i was the index for cluster (RUCCs in this model), and j was the index for county

Results

Population description

The average annual county-level age-adjusted all-cause mortality rate was 8.19 deaths (5.78, 10.60) per 1,000 population. The mortality rates were 2.49 (1.43, 3.55) for heart disease mortality, 1.97 (1.44, 2.50) for cancer mortality, and 0.61 (0.32, 0.90) for stroke mortality. The mortality rates varied across RUCC and climate regions (Table 1). In general, RUCC-stratified mortality rates were the highest in less-urbanized areas (RUCC3) and the lowest in thinly populated areas (RUCC4). Among climate regions, mortality rates were the highest in the humid subtropical region and the lowest in the dry continental region.

Associations between EQI and mortality for the contiguous U.S.

We found positive associations between the overall EQI and mortality for the contiguous U.S., suggesting worse cumulative environmental quality was associated with higher mortality rates. The multiple linear regression models showed that 1 SD increase in the overall EQI was associated with a 3.22% (95% CI: 2.80%, 3.64%) increase in all-cause mortality rate, a 0.54 % (-

0.17%, 1.25%) increase in heart disease mortality rate, a 2.71% (2.21%, 3.22%) increase in cancer mortality rate, and a 2.25% (1.11%, 3.39%) increase in stroke mortality.

The associations varied for EQI domains, and they ranged from -1.27% (-1.70%, -0.84%) to 3.37% (2.90%, 3.84%) for all-cause mortality, -2.62% (-3.52%, -1.73%) to 4.50% (3.73, 5.27%) for heart disease mortality, -0.88% (2.12%, 0.36%) to 3.72% (2.38%, to 5.06%) for stroke mortality, and -0.68% (-1.19%, -0.18%) to 3.01% (2.46%, 3.56%) for cancer mortality (Table 2). Air had the largest associations with all-cause, heart disease, and cancer mortality, while the sociodemographic index had the largest association with stroke mortality.

Associations between EQI and mortality clustered by RUCC.

The associations for hierarchical models clustered only by RUCC were positive for all-cause, stroke, and cancer, mortality for all RUCC groups (Table 3). The associations for heart disease mortality were positive for metropolitan urbanized area (RUCC 1) and negative for other RUCC groups. The ranges of percent difference in mortality rates per 1 SD increase in the overall EQI were 0.21% (-0.55%, 0.97%) to 3.16% (2.33%, 3.99%) for all-cause mortality, -2.73 % (-3.91%, -1.55%) to 0.54 % (-0.45%, 1.53%) for heart-disease mortality, 0.97% (-0.46%, 2.41 %) to 5.62 % (2.82 %, 8.43 %) for stroke mortality, and 1.68% (1.48%, 1.89%) to 2.51 % (2.35%, 2.68%) for cancer mortality.

For domain-specific models we focused on all-cause mortality for brevity. The results for cause-specific mortality can be found in supplemental materials. The domain-specific models clustered only by RUCC resulted in positive associations with all-cause mortality for the air and built indices across all RUCC groups, and negative or null associations for the other domains (Table S4). The ranges of percent difference in all-cause mortality per 1 SD increase in domain-specific

EQI were 2.09% (1.56%,2.63%) to 3.89 % (3.45%, 4.33%) for air, -0.57% (-1.07%,-0.07%) to 0.16% (-0.23%,0.54%) for water, -1.67% (-2.32%,-1.02%) to 0.26% (-0.72%,1.25%) for land, 0.69% (0.35%,1.03%) to 1.38% (0.85%,1.91%) for built, and -1.45% (-2.41%,-0.49%) to 0.32% (-0.28%,0.93%) for sociodemographic index.

Associations between EQI and mortality clustered by climate.

The hierarchical models clustered only by climate also suggested positive associations for most climate regions (Table 3). In general, the associations were higher in the dry climate for the four types of mortality studied. The ranges of percent difference in mortality rates per 1 SD increase in the overall EQI were 2.29% (1.87%, 2.72%) to 5.30% (4.30%, 6.30%) for all-cause mortality, -0.50% (-1.25%, 0.26%) to 1.86% (0.04%, 3.68%) for heart-disease mortality, -1.89% (-4.46%, 0.67%) to 12.36% (7.52%, 17.21%) for stroke mortality, and 1.60% (0.22%, 2.97%) to 4.60% (2.77%, 6.44%) for cancer mortality.

The domain-specific models clustered only by climate showed that air had higher associations with all-cause mortality in all except dry climate region, where the largest association was found for the land index (Table S4). The ranges of percent difference in the all-cause mortality per 1 SD increase in domain-specific EQI were -1.70% (-3.49%, 0.08%) to 4.73% (3.81%, 5.66%) for air, -1.10% (-2.30%, 0.10%) to 1.03% (0.28%, 1.78%) for water, -2.71% (-3.93%,-1.50%) to 13.11% (9.56%, 16.66%) for land, -0.99% (-2.10%, 0.13%) to 3.01% (1.45%, 4.57%) for built, and -1.66% (-2.06%, -1.26%) to 1.51% (0.72%, 2.30%) for sociodemographic index.

Associations between EQI and mortality clustered by RUCC-climate combination.

The models for overall EQI clustered by RUCC-climate combinations reflected the spatial patterns in the models clustered by climate and RUCC separately in general. However, they also

revealed variations related to the unique combination of RUCC-climate (Figures 2 and 3, and Table S8). Positive or null associations between the overall EQI and mortality were observed in most of the contiguous U.S.

The model clustered by RUCC-climate combination also showed that, among the five domains, air had the largest association with all-cause mortality for most of contiguous U.S. (Figure 4 and Table S9), and all the associations for air were positive. The associations between the water index and all-cause mortality were negative or null for most of the contiguous U.S. Positive associations for water were mainly observed in less populated areas (RUCC 2 to 4) in dry continental, hot summer continental, and Mediterranean regions. The associations between the land index and all-cause mortality were larger in rural (RUCC3 and RUCC4) areas with dry and dry continental climates among the RUCC-climate combinations. The associations between the built index and all-cause mortality were positive for the majority of the contiguous U.S. Finally, the associations between the sociodemographic index and all-cause mortality were larger in rural areas (RUCC 3 and 4) with dry climate among the RUCC-climate combinations.

Discussion

We observed mostly positive associations between the overall EQI and mortality rates at the county level in our analyses. Among the environmental domains, the air index had stronger associations with all-cause, heart disease, and cancer mortality compared to other domain indices, and the sociodemographic index had stronger association with stroke mortality. The results also indicated that the associations between environmental quality and mortality vary by RUCC and climate regions.

Our results were consistent with previous work, which showed significant associations between air pollutants and mortality (Zanobetti and Schwartz 2009, Kim et al. 2015). Among the five EQI domains, the air index included the most variables (n=87, water n=80, land n=26, built n=14, sociodemographic n=12) and had best data availability (Messer et al. 2014), which may contribute to a better representation of air quality. This difference in data quality across domains could also explain the heterogeneous associations between the other domains and mortality. It may also be, however, that air quality was most influential for mortality in the U.S.

In our results, large associations (>10%) between mortality and EQI were found for some clusters. The magnitude of these percent difference were higher than findings in previous studies involving air and land environmental quality (Garcia-Perez et al. 2013; Krall et al. 2013; Zanobetti and Schwartz 2009). However, our results for cumulative environmental quality cannot be directly compared with results for single environmental exposures. Furthermore, we reported the result per 1 SD increase in EQI, which may represent a considerable change in the relative cumulative environmental quality (For example, 1 SD increase in the EQI can shift a county from being average to being in the lowest 15% of contiguous states in terms of environmental quality).

We also noted that these large associations were observed mostly in the dry climate region. This region had the smallest number of counties and the largest heterogeneity in all-cause mortality rate (Table 1 and S3), which may result in larger values in the estimates. A previous analysis also found that the associations between fine particulate matter and mortality were stronger in the dry climate region compared to other areas (Zanobetti and Schwartz 2009). Therefore, it may be that intersection of dry climate regions and environmental quality constituted a substantial environmental burden on mortality; possible mechanisms require further investigation.

Although most of the associations between the overall EQI and mortality rate were positive, negative associations were still observed in the analysis, especially for heart disease mortality and for the water, land and sociodemographic indices. These negative associations represented counter-intuitive results suggesting worse environmental quality was linked with lower mortality rates. One possible explanation for the observed negative associations was the spatial scale used in the models. Analysis based on county-level exposure data may be too diffuse for areas with high heterogeneity in population distribution or environmental quality (Messer et al. 2014, Rappazzo et al. 2015). Additionally, the county-level is not the optimal unit of geographic aggregation for all the domains contained within the EQI. The amount of spatial variability within a county may differ among environmental domains. If the particular variables within a domain are homogeneous at the county level they will be better represented than variables that are more heterogeneous, which could be a form of exposure misclassification. This may lead to potentially lower effect estimates in the more urban areas where we expect more heterogeneity. An EQI at finer spatial scales (such as census tract) and studies that explore environmental effects at multiple spatial scales may shed light on these counter-intuitive results.

As this research is novel, it is exploratory in nature and not driven by a priori hypotheses. In our analysis we explored the spatial patterns in the associations between mortality and EQI by RUCC, by climate, and by the combination of RUCC and climate. The hierarchical models shrank the estimated associations for each cluster toward the average associations for the contiguous U.S. (partial pooling). This shrinkage made comparisons among the clusters more conservative compared to stratified analysis (Gelman et al. 2012). In lieu of null hypotheses testing, we examined patterns of the estimated associations between EQI and mortality and

focused on their magnitude and precision (95% CI), rather than their statistical significance, thereby not raising multiple testing concerns.

A limitation of the analysis was its ecological design and cross-sectional nature. In this study we associated 2000-2005 EQI with mortality rates in the same period. Thus the results were likely to represent the health impact of environmental quality in relatively short time period. We believe this focus on cross-sectional associations was appropriate considering the short-term associations between environmental quality and mortality reported in many of the previous studies, in particular for air quality (Ostro et al. 2011; Tao et al. 2012; Zanobetti and Schwartz 2009). Additionally, if the county level environmental quality remained relatively stable, such that the 2000-2005 EQI also reflected county-level environmental quality of previous years, the associations in this study can be generalized to health impact of environmental quality outside the six-year time period. An analysis with current EQI and delayed mortality rates may help reveal the long-term effects.

In this study, we used the EQI and its domain indices as continuous variables in models, assuming a linear relationship between the EQI and the log of mortality rates. This modeling decision may be considered another potential limitation of our analysis because environmental quality can exhibit complex nonlinear impacts on mortality. However, our exploratory graphical analysis did not reveal apparent deviations from linearity (results not shown). Furthermore, the linear assumption leads to straightforward interpretation of the results. The linear model used can also represent the average association of EQI with log mortality across environmental quality gradient, and thus reflect the general trend in the relationship. So while limiting, we viewed this approach to be the most appropriate for this exploratory analysis.

A key strength of this study was the use of the EQI to represent cumulative environmental quality. It combined multiple domains at the county-level and provided coverage for the entire U.S, both of which represent improvements over other environmental indices (Messer et al. 2014). Compared to previous studies using single exposures, the use of EQI was more likely to capture the health effects resulting from the overall burden of environmental exposures. The five domains of EQI also provided a way to compare the health impacts of different aspects of environmental quality. This is the first study in the United States, to our knowledge, which assessed the cumulative environmental effects on mortality.

Another major strength of this work was its national scale and its inclusion of spatial heterogeneity via urbanicity and climates. The three ways of regional clustering (RUCC, climate, and RUCC-climate combined) allowed us to explore the spatial patterns in the associations between EQI and mortality across the contiguous U.S. Compared to studies restricted to a smaller spatial scale and studies at the national level but without spatial heterogeneity, this study has the potential to show the difference in the environmental impact on mortality, which may offer information for prioritizing efforts in addressing environmental problems.

Conclusions

This study was the first attempt in the United States to assess the cumulative environmental impact on mortality and its spatial patterns. We found positive associations for the majority of the contiguous U.S., suggesting adverse effects of poor cumulative environmental quality. We found that among the five EQI domain indices, air had the largest associations with all-cause, heart disease, and cancer mortality, while the sociodemographic index had the largest association with stroke mortality. The associations varied for urbanicity and climate regions, suggesting

different environmental impacts on mortality across the contiguous U.S. Particularly, large associations were found in the dry climate region. This work demonstrated the use of EQI as a useful tool to assess the cumulative environmental burden at the county level, and the use of the five domains indices of EQI to assess the co-occurring environmental impacts.

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Tables

Table 1. Mean (and 95% CI) age-adjusted death rates per 1000 population and number of counties (n) in RUCCs¹ and climate regions, contiguous United States 2000-2005

RUCC/Climate	All-cause	Heart disease	Stroke	Cancer
RUCC1 Metropolitan-urbanized	8.18 (6.06,10.30) n=1085	2.42 (1.50,3.34) n=1084	0.59 (0.34,0.84) n=1069	1.98 (1.51,2.45) n=1085
RUCC2 Non-metro urbanized	8.28 (6.26,10.30) n=319	2.48 (1.52,3.44) n=319	0.60 (0.33,0.87) n=319	1.98 (1.55,2.41) n=319
RUCC3 Less-urbanized	8.4 (5.91,10.89) n=1049	2.59 (1.45,3.73) n=1049	0.62 (0.29,0.95) n=1020	1.99 (1.44,2.54) n=1048
RUCC4 Thinly populated	7.8 (5.00,10.60) n=648	2.43 (1.27,3.59) n=615	0.61 (0.34,0.88) n=439	1.92 (1.27,2.57) n=605
Dry climate	7.54 (5.31,9.77) n=65	2.16 (1.24,3.08) n=63	0.48 (0.28,0.68) n=52	1.75 (1.18,2.32) n=62
Dry continental climate	7.17 (5.05,9.29) n=212	1.96 (1.25,2.67) n=204	0.56 (0.32,0.80) n=147	1.72 (1.13,2.31) n=202
Hot summer continental climate	7.73 (5.57,9.89) n=538	2.35 (1.53,3.17) n=524	0.58 (0.34,0.82) n=490	1.93 (1.46,2.40) n=523
Humid subtropical climate	8.77 (6.59,10.95) n=1662	2.72 (1.70,3.74) n=1656	0.65 (0.34,0.96) n=1569	2.06 (1.53,2.59) n=1649
Mediterranean climate	7.39 (5.90,8.88) n=133	2.02 (1.39,2.65) n=132	0.60 (0.44,0.76) n=124	1.86 (1.49,2.23) n=132
Warm summer continental climate	7.44 (5.83,9.05) n=491	2.23 (1.43,3.03) n=488	0.52 (0.32,0.72) n=465	1.89 (1.52,2.26) n=489

¹ RUCC: Rural-Urban Continuum Codes

Table 2. Percent difference (and 95%CI) in mortality rates per 1 standard deviations increase in EQI domain indices from the multiple linear model

EQI domains	All cause	Heart disease	Stroke	Cancer
Air	3.37 (2.90,3.84)	4.50 (3.73,5.27)	-0.88 (-2.12,0.36)	3.01 (2.46,3.56)
Water	-0.26 (-0.59,0.08)	-1.70 (-2.25,-1.15)	0.50 (-0.32,1.31)	-0.56 (-0.95,-0.17)
Land	-1.27 (-1.70,-0.84)	-1.81 (-2.51,-1.11)	-0.65 (-1.69,0.39)	-0.68 (-1.19,-0.18)
Built	1.19 (0.77,1.60)	-0.77 (-1.48,-0.05)	1.04 (-0.12,2.20)	0.09 (-0.43,0.61)
Sociodemographic	-0.31 (-0.86,0.24)	-2.62 (-3.52,-1.73)	3.72 (2.38,5.06)	0.60 (-0.05,1.24)

**Table 3. Percent difference (and 95%CI) in mortality rates per 1 standard deviations
increase in overall EQI from the models clustered by RUCC and by climate separately**

RUCC / Climate	All-cause	Heart	Stroke	Cancer
RUCC1 Metropolitan urbanized	2.28 (1.63,2.92)	0.54 (-0.45,1.53)	0.97 (-0.46,2.41)	2.51 (2.35,2.68)
RUCC2 Non-metropolitan urbanized	1.46 (0.09,2.82)	-0.85 (-2.67,0.98)	5.62 (2.82,8.43)	2.05 (1.74,2.35)
RUCC3 Less urbanized	0.21 (-0.55,0.97)	-2.73 (-3.91,-1.55)	3.94 (2.46,5.43)	1.68 (1.48,1.89)
RUCC4 Thinly populated	3.16 (2.33,3.99)	-1.44 (-2.85,-0.03)	2.25 (0.68,3.82)	1.85 (1.53,2.17)
Dry climate	5.30 (4.30,6.30)	1.86 (0.04,3.68)	12.36 (7.52,17.21)	4.60 (2.77,6.44)
Dry continental climate	3.70 (2.89,4.51)	0.75 (-0.78,2.29)	2.38 (-1.69,6.45)	1.60 (0.22,2.97)
Hot summer continental climate	4.24 (3.56,4.93)	1.49 (0.22,2.75)	-0.62 (-3.24,2.01)	3.47 (2.43,4.50)
Humid subtropical climate	2.29 (1.87,2.72)	-0.50 (-1.25,0.26)	2.65 (1.47,3.84)	1.84 (1.27,2.41)
Mediterranean climate	3.46 (2.32,4.60)	1.75 (-0.04,3.53)	4.66 (0.43,8.89)	2.66 (0.97,4.35)
Warm summer continental climate	3.92 (3.15,4.68)	0.60 (-0.70,1.90)	-1.89 (-4.46,0.67)	3.75 (2.70,4.80)

Figures legends

Figure 1. Maps for the condensed RUCC (a), condensed climate regions (b), and rescaled overall EQI (mean=0 and standard deviation =1) in the contiguous U.S. Maps were downloaded from U.S. Census Bureau 2000 TIGER products and reproduced using R version 3.0.3

Figure 2. Percent difference in all-cause (a), heart disease (b), cancer (c), and stroke (d) mortality rates for the year 2000-2005 per 1 standard deviation increase in the overall EQI estimated from the models clustered by RUCC-climate combination. Maps were downloaded from U.S. Census Bureau 2000 TIGER products and reproduced using R version 3.0.3

Figure 3. Percent difference (mean and 95% CI) in all-cause (a), heart disease (b), cancer (c), and stroke (d) mortality rates for the year 2000-2005 per 1 standard deviation increase in the overall EQI estimated from the models clustered by RUCC -climate combination. Climate regions: D – Dry; DC – Dry Continental; HSC – Hot Summer Continental; HS - Humid Subtropical; M – Mediterranean; WSC - Warm Summer Continental. The number 1-4 represent RUCC1 to RUCC4.

Figure 4. Percent difference in all-cause mortality rate for the year 2000-2005 per 1 standard deviation increase in the air (a), water (b), land (c), built (d), and sociodemographic (e) index estimated from the models clustered by RUCC-climate combination. Maps were downloaded from U.S. Census Bureau 2000 TIGER products and reproduced using R version 3.0.3

Figure 1.

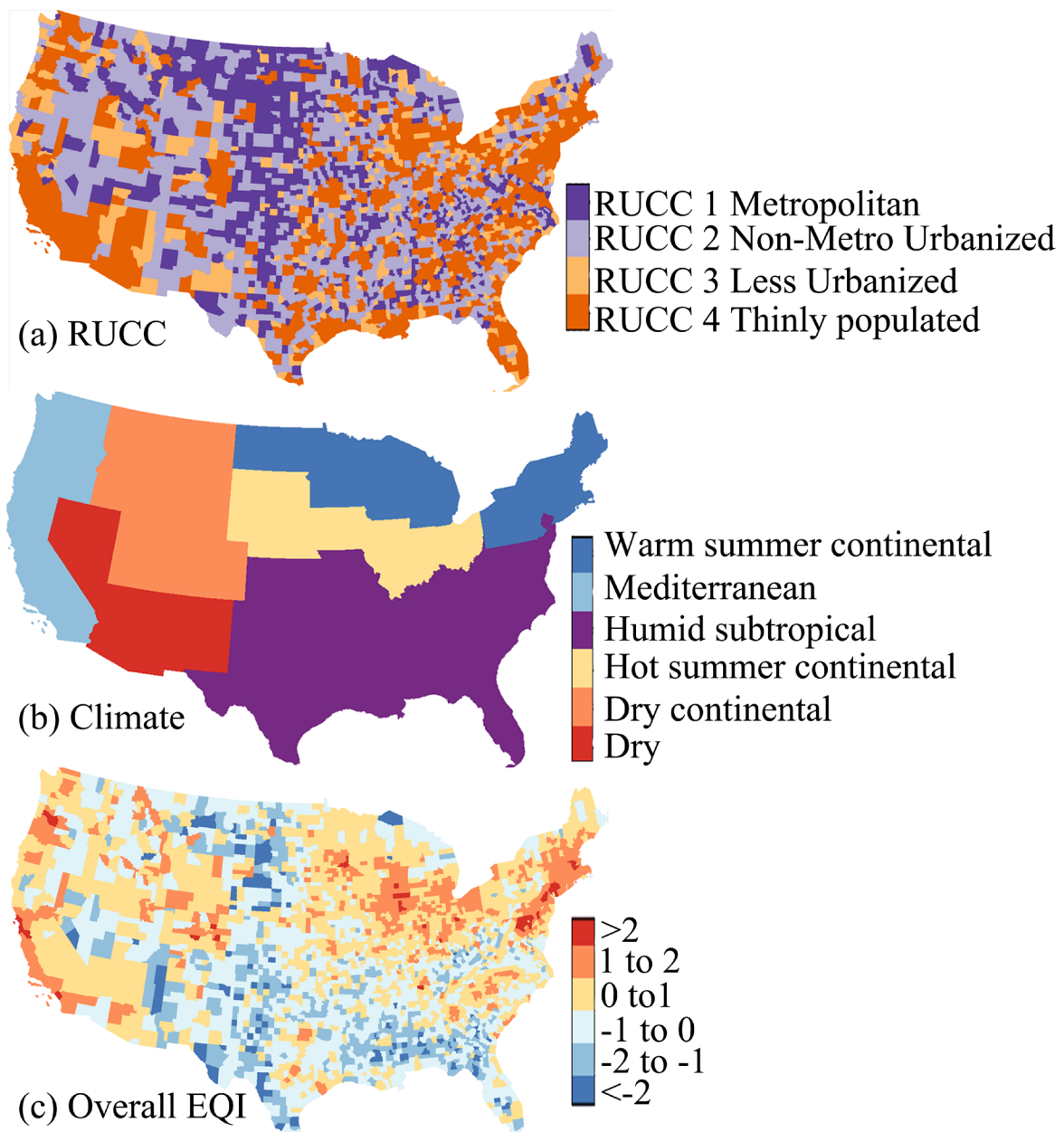


Figure 2.

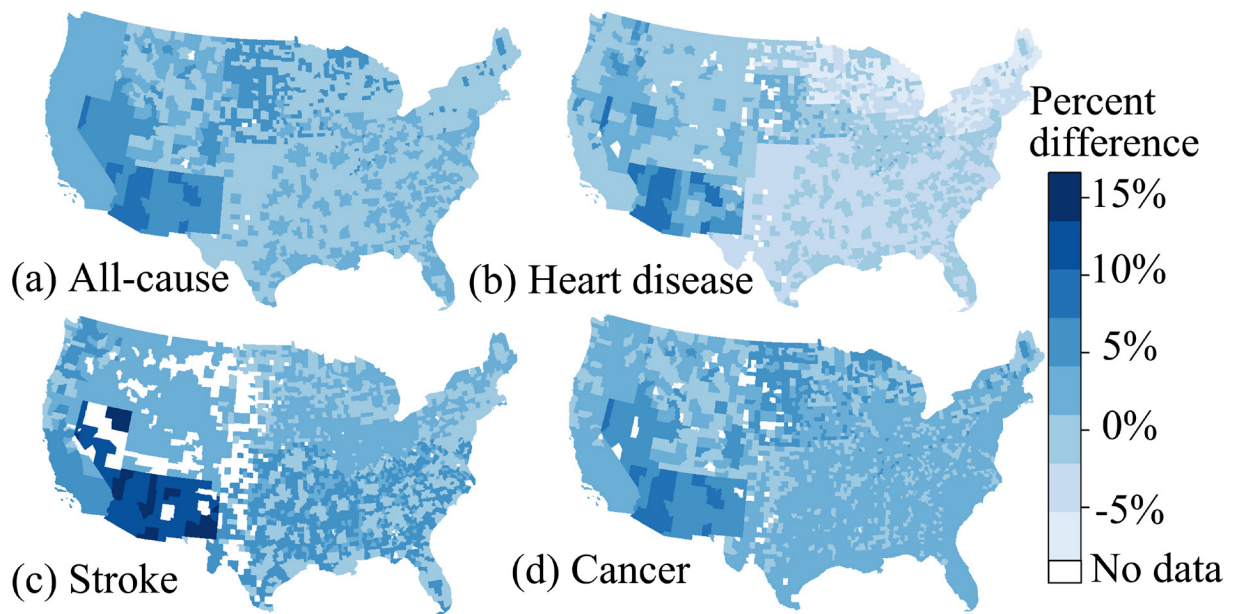


Figure 3.

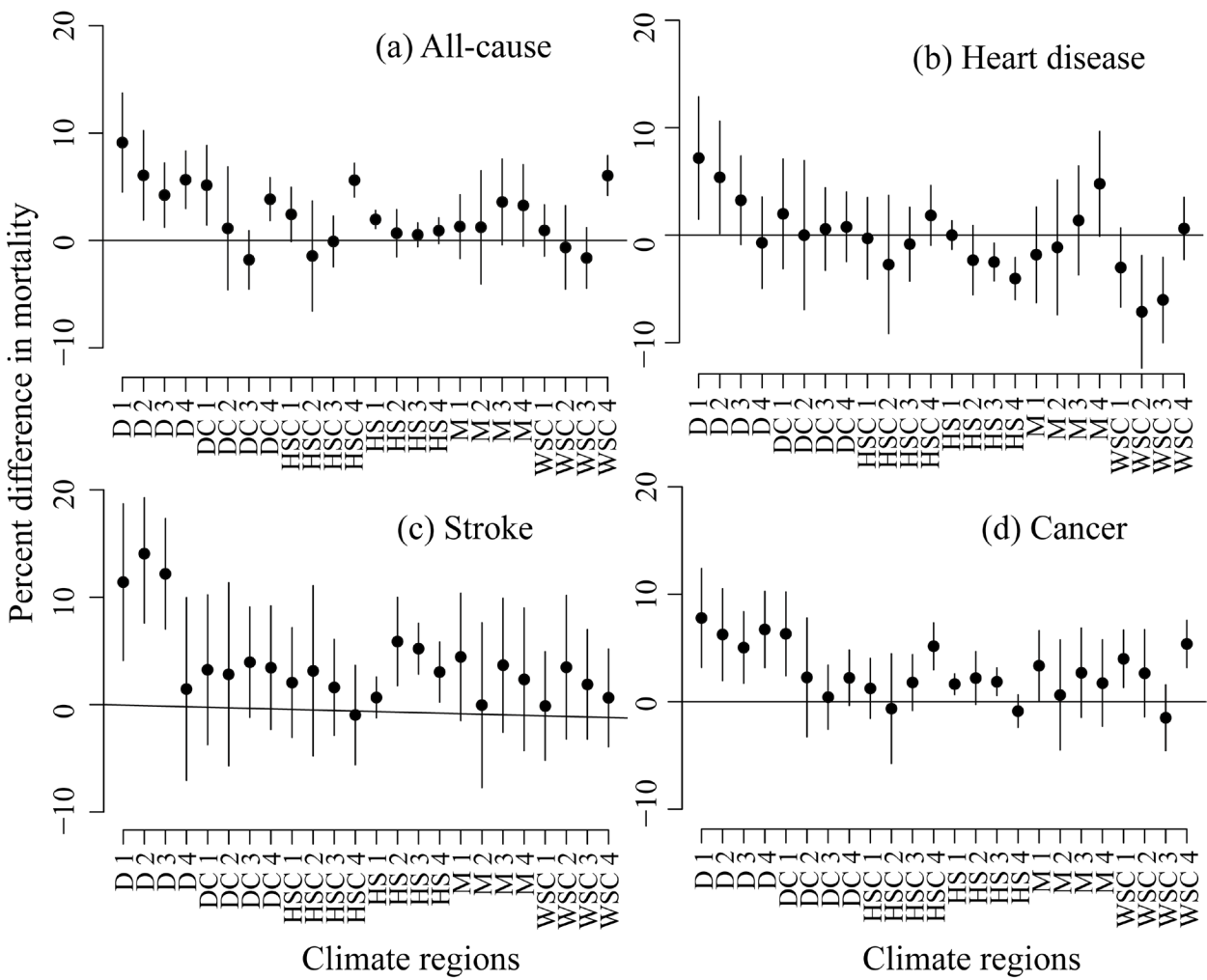


Figure 4.

